AQUATIC SYSTEMS' POTENTIAL TO RECYCLE ORGANICS AND TO DELIVER FFISH: APPLYING A PRINCIPAL AGENT FRAMEWORK TO NATURE SERVICE

Ernst-August Nuppenau
University of Giessen, Germany, Department of Agricultural Policy, Ernst-August.Nuppenau@agrar.uni-giessen.de

ABSTRACT

There is much talk on recycling organic effluents, closing nutrient cycles, maximising energetic efficiency, maintaining equilibriums between humans and nature, etc., even for lakes and estuaries. Aquatic systems provide us (humans) the service of recycling decomposable organics and deliver fish at the same time, notably, as long as the system (nature) is not out of order. The potential of an aquatic system to provide nature services depends on maintaining the specific equilibrium of that system. We explore the dependency of this equilibrium on human activities that help to improve eco-system functioning; though human activities are costly and nature is not for free. As will be shown, only costly oxygen provision and labour as input improve the system. However, it is difficult to evaluate services correctly. If catch from outside is cheap and if, as major objective of societies, labour productivity has to be increased, it may not pay to maintain nature services. It is against this background, that we show how nature services can be evaluated more correctly on the basis of an exchange between humans and aquatic systems. We will see how a framework of humans as principle and nature as agents provides a better concept for services evaluation. Humans have to scarify labour for recycling and nature may "require payments". In a suggested new perspective on closing nutrient cycles in aquatic systems, which is based on a system approach where nature provides services to humans, nature has to be paid. Implicitly, we hypothesise that entropy optimised systems may be more sustainable.

Keywords: Recycling, aquatic nature service, human and ecological evaluation,

INTRODUCTION

There is much talk on recycling organic effluents, closing nutrient cycles, maximising energetic efficiency, and maintaining equilibria between humans and nature. Even for lakes and estuaries, which are complex set ups of matter flows and species or taxa that fulfil services for humans, recycling and food provision make them essential for livelihoods. Ideally, we may see nature and humans work together in nutrient recycling and, though as an open system, try to reach minimal losses of nutrients and maximal productivity of nature (organic matter, wasted energy, entropy, etc.: [1]. This perspective worked well to a certain extent in the past under nutrient scarcity and food self-sufficiency, but what is new? In general it seems that nutrient effluence is a big problem, that food is cheap, and that farmers and fisher man care more about cost minimisation in production than about capturing nutrients. Since food and nutrients can be bought from outside places, nutrient management has lost attraction. Especially, aquatic systems provide us (humans) the service of recycling decomposable organics and deliver plankton (primary) and fish (secondary), as long as the system (nature) is not out of order. However, the potential of aquatic systems to provide nature services seem to depend on maintaining an equilibrium between human activities and nature needs for preservation. Though all dynamic feed-back mechanisms are nor fully understood, many studies refer to the role that humans play in eutrophication [2] and ask for cures.

In this paper we start form a different angle and suggest a modelling approach that depicts a likely equilibrium as depend on a principal-agent mode, where we explicitly consider a mutually beneficiary exchange between humans and nature. We explore the dependency of equilibrium on human activities that extract resources (fish), that rely on services (recycling of organic wastes), and help to improve eco-system functioning. But human activities favouring nature are costly and nature is not for free. For instance, costly oxygen provision and labour improve the system, whereas organic pollutants spoil the system. However, it is difficult to evaluate services correctly and find the equilibrium. If catch (food) from outside is cheap and, as an objective of societies, labour productivity has to be increased, it may not pay to maintain nature services and lakes die. It is against this background, that we show how nature services can be evaluated more correctly on basis of an exchange economy between humans (aquaculture) and nature (aquatic system). We show how a framework of humans as principle and nature as agents provides a concept for better services evaluation. This framework has been suggested for the evaluation of a true exchange between humans in nature [3].

The idea is that humans may have to scarify resources, "labour-leisure", for recycling services of nature, and nature may get "payments". At a first glance that looks merely as a compensatory requirement; but at a second glance, humans can benefit from payments by improved services, so it is a matter of modelling exchanges between nature and humans. In order to maintain system functioning or even foster functioning of eco-systems, in a sense, that we appreciate fitness of eco-systems as a goal to be modelled, we will show that this understanding gives new insight in interactions between humans and nature. Presumably, this approach implies that eco-systems have evolved along scarcities and humans can help nature to circumvent scarcities. In particular we explore nutrient cycles in nature based on accumulation and decomposition. In the paper we suggest a new perspective on closing nutrient cycles in aquatic systems which are based on a system approach. Basically such nutrient cycles are modified by humans. Nature provides environmental services to humans and nature may require payments, notably expressed in human categories. So humans decide on the exchange. Alternatively, one could hypothesise that entropy optimised systems may be more sustainable. Then nature may "decide" and we have to switch the setting of who is superior. We confine our approach to humans as principals and nature as agent.

CONCEPTUAL OUTLINE AND BASIC FRAMEWORK

In brief, our approach works with four behavioural units or ecological compartments. Figure 1 provides an overview. We start with Figure 1a which is a simplified description of a natural organic-nutrient cycle. (1) We have an accumulating unit, plankton. It uses nutrients in a lake, as decomposed from fish, and sunlight to build up biomass being species. To explain processes, we take an economic-like approach of revealed preferences, applied to nature, to see how organic matter production and species composition are given priority. This setting implies that a conceptual framework of fitness optimisation is given, which has a focus on biomass [4,5,6]. As a result we can "explain" observable specie combination; especially the sizes of populations are retrieved from structural parameters that delineate "behaviour". We presume that "behaviour" has been designed by evolutionary processes. But we do not go into the evolutionary process [7] as such, which has brought up the system fitness, rather think that terms like "cost" (see below) are even not unusual in ecology, especially, when it comes to the explanation of feeding behaviour. Just let us think that the following economic like setting allows us to derive parameters that depict the system. However, we introduce an organic matter using unit (fish) that delivers nutrients to plankton by converting organics. It means applying an approach of revealed goals and outline of observable behaviour. Our conceptual, economic like, outline of nutrients and organic matter flows has a goal, fitness. Fitness is considered "teleonomic" wise not "teleologic" wise, which means that we use, apparently for description a quasi objective, we use it for explanation. The task is nutrient or organic matter acquisition which reveals or expresses the fitness and function-ability of the system. Note, no deeper structural insight is needed as revelation. It enables us to link functional aspects to humans work with revelation of "behaviour" of accumulating and decomposing units, being fish and plankton. In Figure 1b we add an aquaculture and organic waste management unit, though not connected. In this case humans are exogenous and artificially fish are nourished to produce food; food is consumed and remains are dumped exogenously to the system. Remains include residues, animal waste, and perhaps excrements. Moreover, to describe the food system as economically viable, fish farmers receive money and the system is viable as long as exogenous factors like income, labour, and energy are brought into the system. The economic system is described by financial, food, and energy flows as well as increasing system occupation. The human systems may be so strong that the natural system diminishes; both are decoupled, i.e. humans don't need to recognise eco-systems, or see it as dump ground? In contrast in Figure 1c we see

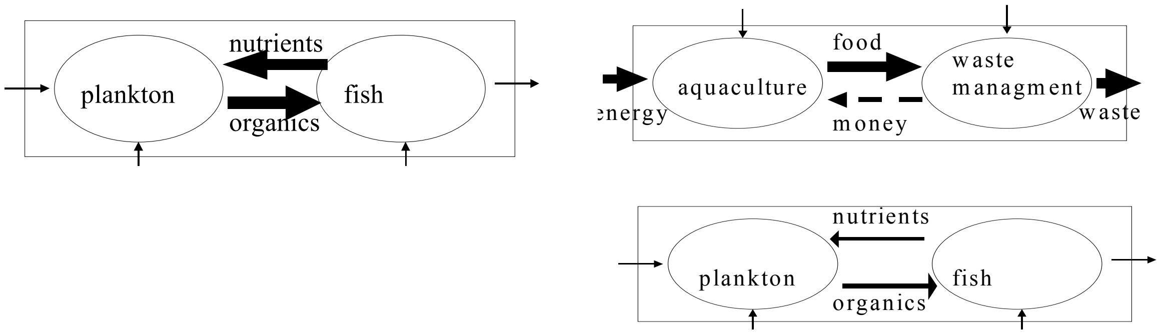

Figure 1: a. Natural System of Recycling **b. Disconnected Farming and Waste Management**

how the systems could evolve by linking physical exchanges to each other. Three types of physical service/exchange are explicitly modelled. (1) The decomposing unit takes over parts of the function of a human waste treatment unit by decomposing organic remains into plant nutrients. (2) Plankton is supplied to aquaculture as organic matter. (3) We assume that a healthy nature supports aquaculture offering a balance of plankton and fish, including diversity of the eco-system. In all there respects we need to comment on specific roles, functions, flows of service, payments, etc.

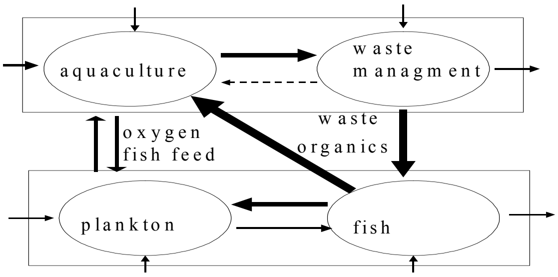

Figure 1c: Connected Recycling System

With respect to the role of plankton we have to keep in mind that an equilibrium (steady state) has previously existed in a natural environment, characterising the energy and nutrient flows as mutually dependent on each other. Hence, as a reference we have to reveal by modelling how organic matter flows, shifted healthiness and fitness of the eco-system are linked if humans are involved. Obviously that relates to both, accumulating and decomposing units.

BASIC MODEL OUTLINE AND DERIVATION OF BEHAVIORAL EQUATIONS

Fishes, Plankton, and Nature in Flow Equilibrium

A first step is to "describe" a fish-plankton eco-system under the criteria of a goal oriented and system optimising behaviour [8]. We simplify and call any photosynthesis organism "plankton" and any user "fish". This is not the 'truth', rather it is a research hypothesis that helps us to reveal "behaviour" of fish prevalence. It is human thinking, but hereby we obtain a composition of the system that is goal oriented [5] and that describes physical flows by means of nutrient and organic matter exchange [6]. As humans we are given the task to describe a flow-system that includes 2 compartments: (1) a compartment producing plankton on the basis of sunlight, nutrients and oxygen, and (2) a compartment using and later decomposes into nutrients. This is not hundred percent successful (open). Quasi-goals are:

$$F_p = (1-\varpi)\tau_p s_p + \varpi s_p^{/}(1+s_p) - C_p(s_p - \Phi_{p1} n_f, n_x) + \lambda_{p,1}{}'(n_x + n_f - \Omega_{p2}(s_p + \dot{S}_p)) \quad \text{(Eq. 1a)}$$

(Eq. 1a) for plankton species and (Eq. 1b) for fish species

$$F_f = (1-\varpi)\tau_f s_f + \varpi s_f^{/}(1+s_f) - C_f(\Omega_{f1} s_f + \Phi_{f1} n_f - s_p) + \lambda_{f,1}{}'(s_p - \Omega_{f,2} n_f - \Omega_{f,3}\dot{S}_f) + \lambda_{f,2}(1^{/}\,\Omega_{f4} s_f - o_f) \quad \text{(Eq. 1b)}$$

where variables are and "p" stands for an accumulation plankton compartment and "f" for a decomposing fish compartment:
F_p = fitness of accumulating plankton compartment
F_f = fitness of decomposing fish compartment
s_p = vector of species of plankton compartment (capital letter with dot indicate growth)
s_f = vector of species of fish compartment (capital letter with dot indicate growth)
n_f = vector of plankton nutrients from fish decomposition
n_x = vector of plankton nutrients from external source
o_f = available oxygen for fish.

For decomposing, "fish" (including micro organisms), and accumulating, "plankton" (including water plants), equations (1a and b) constitute a basic description of the fitness seeking eco-system, since net values of organics are envisaged. The description is from a human perspective: I.e. this system has to recognise nutrient and organic matter flows and balances, and it "was" optimised. Note, coefficients Ω and Φ are different: Φ gives the technology level of acquisition potential; losses can occur, though "by evolution costs are minimised". Ω gives a balance of achieved conversion in a mode of a matter flow analysis. (Eq. 1a and Eq. b) are mathematical expression of a quasi-goal function. Each goal (fitness) function contains two straight elements. (Eq. 1) The positive component is organic matter production as contained in the number of species multiplied by a bodyweight "τ_a s_a ", also we added a biodiversity measurement "$\Sigma_a\, s_a \ln(s_a) \approx s_a^{/}(1+s_a)$. The negative element is a loss function "C(…)". Losses are associated with procurement of organics. We interpret costs as loss of potential organics (increase of entropy). Some free energy has to be used (is lost) while catching as much nutrients as possible [1]. The difference to usual thinking is that conversion is incomplete; in other words, evolution has minimised losses (costs) but not eliminated. A loss "s_l" is an argument in a quasi "cost function" on, for instance, $s_l = s_p - \Omega_{a,1} n_p$. An analogous argument applies to the fish (plankton feeding) compartment. Availability of organics from accumulating plankton and transforming it into organics of fish is incomplete (costly, i.e. energy consuming). Finally, we may think of inter-temporal storage of organics in compartments (differential equations as first moments, i.e. a dot on top of S serves as indication). For instance, this means that plankton can grow and, in general, species mass can be stored [7]. But, essentially, matter flow (population growth) is limited to the availability of organics. A reverse is also true: an accumulator (plankton) is confronted with limited decomposed nutrients. We may add natural inflow. There is a stead state, though it can fluctuate. For reducing complexity we focus on flows and consider stocks as a matter of further analysis. We work with a mature system; i.e. we do not consider processes that brought it up. Finally, on resources we consider a lake, estuary, or another self-contained system with limited oxygen.

Then, we have to specify cost functions as treatable mathematical formulations. We simplify assume cost components are quadratic, i.e. losses increase progressively, if species increase.

$$C_p(.) = \psi_p^{/} s_p - s_p^{/}[0.5\Psi_{p,1}(s_p - \Phi_{p1} n_f)] + s_p^{/}\Psi_{p,2} n_x \qquad \text{(Eq. 2a)}$$

and

$$C_f(.) = \psi_f^{/} s_f + s_f^{/}[\Psi_{f,1} s_p - .5 \cdot \Omega_{f1} s_f - \Phi_{f1} n_f] \qquad \text{(Eq. 2b)}$$

This assumption is driven by pragmatism. The advantage can soon be seen, since such quadratic formulations provide linear behaviour and a set of feasible equilibria.

Nature's behaviour and equilibrium

The fruitfulness of the above quasi-goal function of fitness appears when we derive "behavioural equations". Behaviour in economics is defined as optimal behaviour (best fitted); behavioural equations are normally first order derivatives of goal functions. Taking the above goal functions and the supplementary functions with quadratic cost components we can derive linear "behavioural equations" as revealed behaviour; though note, concerning the composition of species in (3), we have to think of partial and system analyses. Individual optimisation (compartment wise) is partial but due to equilibria we get a system analysis. The optimisation of fitness provides a system of linear equations for plankton:

$$\begin{aligned} \delta F_p / \delta s_p &= \tau_p + \varpi\, s_p - \psi_p + \Psi_{p,1} s_p - \Psi_{p,1}\Phi_{p1} n_f + \Psi_{p,2} n_x - \Omega_{p2}\lambda_{p,1} = 0 \\ \delta F_p / \delta\lambda_{p,1} &= n_x + n_f - \Omega_{p2}(s_p + \dot{S}_p) = 0 \end{aligned} \qquad \text{(Eq. 3a)}$$

and fish:

$$\begin{aligned} \delta F_f / \delta s_f &= \tau_f + \varpi s_f - \psi_f + \Psi_{f,1} s_p - \Omega_{f1} s_f - \Phi_{f2} n_f + \Omega_{f3}\lambda_{f,2} = 0 \\ \delta F_f / \delta n_f &= -\Phi_{f1} s_f - \Omega_{f,2}\lambda_{f,1} = 0 \\ \delta F_f / \delta\lambda_{f,1} &= s_p - \Omega_{f,2} n_f - \Omega_{f,3}(s_p + \dot{S}_f) = 0 \\ \delta F_f / \delta\lambda_{f,2} &= 1^{/}\,\Omega_{f3} s_f - o_f = 0 \end{aligned} \qquad \text{(Eq. 3b)}$$

Given that the technical specification of the above functional compartments of nature is sufficient, interactions are retrievable by statistics. By the system (Eq. 3a and b) we receive an explicit determination of system behaviour. It could also be stated ad-hoc. The advantage of deriving it from a goal function is the possibility to make inferences from observation to the "unveiled" goal: "fitness". A major problem is that the system would initially contain 3 endogenous variables: s_f, s_p, n_f. If no restrictions, for instance, on oxygen are introduced the system is not scaled. But, by linking flows there can be an equilibrium between plankton, fish and nutrients. For instance we assume that a proportion (Eq. 3c) was "designed" in nature, and humans observe this, as "given" by evolution; an equilibrium is:

$$s_f = \Omega_T s_p \qquad \text{(Eq. 3c)}$$

The idea is again to go along observation and make inferences. Now, system (3) includes all major elements of system behaviour. The system (Eq. 3) can be perceived as a causal system, where an equilibrium exits between an accumulating unit of organic matter and a decomposing unit, but also as a quasi-goal oriented system, where “fit” means a system being optimal (optimally adapted). By using this argument we operate with a duality of conceptual explanation: modelling and system description. Note, our description of the system depends primarily on the composition and size of species in each compartment and it also involves nutrient flows. Furthermore, it is positive and normative in a specific sense. In particular it contains coefficients that can be retrieved from the particular system behaviour. To clarify: we may help ourselves thinking that nature has arranged a proportional composition, made up of species, nutrient flows, and diversity. And we merely use “our” optimisation as a tool to describe "nature's technology”, i.e. ex-post. Then, we reckon the emergence of a composition of species as a black box; and we merely try to delineate nature’s plan from observation.

As an immanent way to describe relationships in (Eq. 3c), we assume a transformation matrix of organics between accumulator and decomposer exists, and this is measurable. Alternatively, we may assume a limitation in oxygen as given in (Eq. 3’). Then we see multiple use of oxygen and use as transformation. We do not go into oxygen production. This enables us to specify the oxygen restrictions more complex in order to retrieve the coefficients.

$$o_0 = 1'o_f + 1'o_p = 1'\Omega_{T,p} s_f + 1'\Omega_{T,p} s_p \qquad \text{(Eq. 3c`)}$$

(Eq. 3c’) restricts resource use. Apparently, plankton normally needs only minor amounts of oxygen, because it also produces oxygen using sunlight and carbon dioxide. It can be omitted in an oxygen equation. Alternatively we can make it “-“ as a delivery and omit o_0. At least a restriction in the use of oxygen is good when we later refer to aquaculture and competition for resources. If we are capable of solving the above system for endogenous variables s_a, s_d, n_d, we have a system description as related to flows and fitness. Inserting the variables gives the flow analysis and the fitness functions are dependent on exogenous variables. Furthermore, all nutrients are flow related and are counted in species numbers. This needs some interpretation: species are restricted by oxygen use and nutrient, available in the system. Scarcity prevails as a factor shaping composition optimality. A crucial thing is that we can retrieve the same result (Eq. 3) if we derived it from a unified objective functions or from metabolisms. System fitness can be described by system behaviour. The subsequent idea is: A unified objective function for fitness of nature contains elements on which humans have an impact. The system fitness is changeable. This aspect is important for a joint evaluation of eco-fitness and human welfare.

First introduction of humans as fish farmers and idea of linkage

In our context, humans have two types of interest: to get fish from aquaculture and to get rid of organic waste. Humans use the aquatic system, a lake, as source and dump site though they have to recognise system health, i.e. fitness. Especially problems may emerge with oxygen. The immediate step is to link the above concept of nature fitness to aquaculture and recycling. Three crucial sub-themes become involved: (1) the mode of exchange, (2) the way in which interactions can help us to improve the performance of both, the natural and the human system, and (3) the question of how one can redirect the system towards a viable equilibrium between humans and nature. Also, we have to recognise that the model of linking of an eco-system to a human system involves not only harmonic elements, rather it immediately raises questions of competition and resource scarcity. In particular, we will look at a situation where aquaculture depends on oxygen. Also aquaculture is positively influenced by natural fish population and uses plankton form a natural system (as feed). To achieve a fairly general exposure, which enables us to see classification as corner solutions we start, in equation (4), with a description of aquaculture looking already at the above eco-system depiction. As interface we consider elements for exchange: plankton, labour, and oxygen to improve the system:

$$U_a = p_s s_{a,f} - p_m n_m - p_o o_h - C_h(s_{a,f}, s_f, s_{p,a} + n_m, l_a) + \mu_{f,1}[1 - I'[l_a + l_f]\cdot 1] - \rho' 1_f' \Phi_a l_f + \mu_{f,2}[o_t + o_h - o_p - o_f - 1' \Phi_{a,1} s_{a,f}] \quad \text{(Eq. 4)}$$

where additionally:

U_a = utility of aquaculture farming measured as profit
$s_{a,f}$ = vector of species raised on fish farms and sold
o_h = oxygen of human infiltration
$s_{p,a}$ = vector of plankton species that is consumed in aquaculture
n_m = nutrients purchased to feed for fish on aquaculture farms substituting plankton
l_a = labour in aqua-culture farming
l_f = labour to nature for fish care (for instance breeding natural species)

The formulation (Eq. 4) seems to be sufficient for an exchange, i.e. an "eco-eco-nomy” or “eco^2-nomy". Note that we deal with a human population that makes a living from a fish eco-system and is willing to pay by labour and oxygen as services. Especially, some elements must be altered. In particular, large aquaculture operations mean strong resource pressure. This aspect will be discussed later. The system limits are recognised, and we must contemplate on recycling of fish products to eco-systems as nutrients and inclusion of humans. An immediate solution is to think that humans need food as organic matter. Assuming a proportional element between fish residues and food we can substitute parts of organic matter lost from natural fish with residues. The situation may even improve for nature since farmers have access to animal feed and an initial limited access to nutrients is augmented. To simplify by equation

$$s^{*}_{a,f} = (I-\Omega_{R,1})s_{a,p} ...and... s^{*}_{a,p} = \Omega_{R,2}n_{a,p} \Leftrightarrow s^{*}_{a.f} = (I-\Omega_{R,1})\Omega^{-1}_{R,2}n^{*}_{a,p} \qquad \text{(Eq. 5)}$$

where additionally:

$n_{a,p}$ = vector of nutrients from species raised in aquaculture

a transformation is introduced. We see farmers providing organic matter as converted nutrients. Technically more losses occur than natural. Similar thoughts on waste will follow as demand for organic matter increases. Introducing this helps to reformulate interfaces between nature and human compartments. Then we can see nature as agent.

MODIFICATION OF OBJECTIVES IN BEHAVIOURAL EQATIONS FOR FITTING IN PRINCIPAL-AGENT-NEXUS

Nature as agent

Most importantly, we have to think about a type of payment for nature's service. Payments or compensations are important because they are part of a principal agent framework. Practically payments are quasi incentives. Labour can also be a "payment" if it encourages nature or improves nature to extract services. Apparently, money would not fit into nature's interest, so we take labour, nutrients, and oxygen. As will be discussed, we look at a physical exchange, which is beneficiary for both systems. For this purpose oxygen becomes involved, and the model will include a section on competition for organics and oxygen, notably between plankton, fish and aquaculture. Payments raise the question of property right in an exchange.

Also, in a yet to be designed principal agent framework we firstly have to clarify rights issues such as: are we assuming that aquaculture has the right to use oxygen i.e. is it in the interest of humans to use less oxygen or to deliver even more costly oxygen; humans may have to concede rights: rights problems are between waste and aquaculture. There are reasons to see services in a context of pollution. The reason for putting service provision in a conceptual outline, as above, is to understand the consecutive arguments for system fitness, its evaluation, and a joint evaluation of services and exchange optimisation. Figure 2 shows the various links.

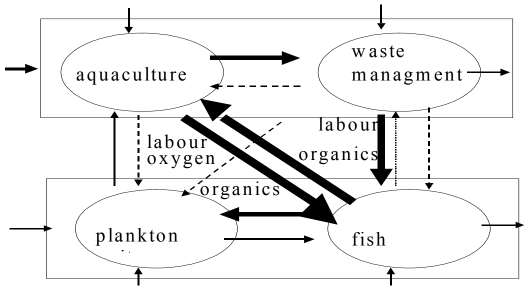

Figure 2: Integrated System

Principally we have to qualify how aquaculture has an impact on organic matter production and use in the ecosystem. We assume that there is a one-to-one substitution of plankton used and feed for fish bought from outside. However, it is critical to think about this qualification, because we assumed in the initial outlet that there is a pre-determined equilibrium between species in the plankton and fish compartments which can be empirically addressed by regression on biomass. Note, organics used by humans reappear in nature, for instance, as residues from fish food and they can be a major determinant as nutrient in the aquatic system. To proceed, in the objective functions introduced, we now, (1a'), see an externally nutrient inflow, which is imposed by human waste being equally treated like fish and nutrients. Nutrients come from waste management partly imposing stress. Imposing stress means that the costs of recycling are higher.

$$F_p = (1-\varpi)\tau_p s_p + \varpi s_p^{/}(1+s_p) - C_p(s_p - \Phi_{p1}(n_f + n_{a,p}), n_{w,p}, n_x, l_a) + \lambda_{p,1}{}'(n_x + n_{f,p} + n_{a,p} + n_{w,p} - \Omega_{p2}(s_p - s_{p,a} + \dot{S}_p)) \quad \text{(Eq. 1a')}$$

As a further deviation in equation (1a') we see a contribution of human labour to nature's "costs" (reduction) in acquiring nutrients. To perceive this, we, for instance, foresee humans working for better nutrient dispersal: Cleaning parts of the lake, etc. Humans allocate labour that modifies a natural sphere improving the functioning of the eco-system. This could mean any activity that is intended to improve the acquisition of needed nutrients by plankton. We have to focus on the immediate functioning of an eco-system. Humans benefit from contributing labour. Next we have to specify how humans can use further labour with respect to supporting the natural fish compartment, i.e. capacity of fish to use the right level of plankton. We have to specify how they may interfere in natural processes for the purpose of nutrient recycling as influenced by labour. The fish compartment, we suggest equation in (1b'), includes enlarged physical balances. We recognise use of plankton for aquaculture:

$$\begin{aligned} F_f = {} & (1-\varpi)\tau_f s_f + \varpi s_f^{/}(1+s_f) - C_f(\Omega_{f,1}s_f + \Omega_{f,2}n_{f,p} + s_{p,a} - s_p, s_{a,f}, o_f, l_f) \\ & + \lambda_{f,1}^{/}(s_p - s_{p,a} - \Omega_{f,3}n_{p,f} - \Omega_{f,2}\dot{S}_f) + \lambda_{f,2}(1^{/}\Omega_{p3}s_f - o_f - o_h) \end{aligned} \quad \text{(Eq. 1b')}$$

where additionally:

$s_{p,a}$ = vector of use of plankton for fish to be recycled from households by the compartment

In (1b), the introduced human labour reduces losses of organic matter (exergy) or, as to be perceived alternatively, helps to incur increased appropriation and conversion of organics. With respect to obligations, causalities and intensions: human labour indirectly fosters services, fish. Increased fitness (prevalence of natural fish) notably as based on a labour-service-exchange is in favour of humans. By introducing labour as a measure to put nature into a better position, we think about human activities that can improve system fitness. Beware that labour also stands for equipment and devices produced by humans.

4.1.1 Modelling an improvement to deliver plankton and capture of nutrients in nature

The effectiveness of labour with respect to recycling of nutrients, as perceived in this paper, has to be explained in more detail. The argument is as follows: the cost of the plankton compartment (2a) has been introduced as a loss of some structured organics (entropy) in a process of appropriation of exergy; so there is no chance to avoid entropy increase; but losses can be diminished. The plankton growth compartment can be supported by labour (human sphere) to minimise losses. For this we simply use appropriate labour and look at improved material flows. For examples one can think of better dispersal, distribution of waste nutrients at right times, etc. In order to make the approach transparent and applicable to ecology, we have to qualify how labour reaches the "cost function" of plankton. So far we have assumed that costs in a biological context means that species use energy to capture nutrients, and that they seek to minimise energy losses, i.e. appropriate exergy and use energy to appropriate exergy. The context is now: For optimising natural metabolisms, at a certain favourable rates, some energy is "burnt" to maintain for instance temperature for chemical processes. How can humans help? Perhaps improve exposure to sunlight, etc. In economic and technical terms this means that all natural processes (exergy) and costs (loss) may include labour in general terms.

Furthermore remember, that the approach is species oriented, so a labour vector is designed to address species selectively and foster survival in competition for organic matter. Not every species in the decomposition compartment will receive similar attention. Humans will select certain bacteria and put much effort into their survival in order to maximise service received. Most simply we now assume that the initial cost component in the objective function alters to

$$C_p(.) = \psi_p^{/}s_p - s_p^{/}[0.5\Psi_{p,1}(s_p - \Phi_{p1}(n_{f,p} + n_{a,p})] + s_p^{/}\Psi_{p,2}n_{w,p} + s_p^{/}\Psi_{p,3}n_x + s_p^{/}\Psi_{p,4}l_p \quad \text{(Eq. 2a')}$$

and

$$C_f(.) = \psi_f^{/}s_f + s_f^{/}[\Omega_{f,2}n_{f,p} + 0.5\Psi_{f,1}s_f + \Omega_{f,1}(s_{p,a} - s_p)] + s_f^{/}\Psi_{1,2}s_{a,f}, + s_f^{/}\Psi_{1,3}o_f + s_f^{/}\Psi_{f,4}l_f \quad \text{(Eq. 2b')}$$

In economic terms and as a delineation of labour effects, indirect cost functions (2') depict the efficiency of compartments when using labour for a reduction of losses for replicating.

Response function

With the amendments we get a new set of response functions (6) as compared to (3). To receive them, we arrived at new first-derivatives of the goal functions of nature (1'):

$$\begin{aligned}&\delta F_p / \delta s_p = \tau_p + \varpi s_p - \psi_p + \Psi_{p,1} s_p - \Phi_{p1} n_{f,p} - \Phi_{p1} n_{a,p} + \Psi_{p,2} n_{w,p} + \Psi_{p,3} n_x + \Psi_{p,4} l_p - \Omega_{p2} \lambda_{p,1} = 0\\ &\delta F_p / \delta \lambda_{p,1} = n_x + n_{f,p} + n_{a,p} + n_{w,p} - \Omega_{p2}(s_p - s_{p,a} + \dot{S}_p) = 0\end{aligned} \quad \text{(Eq. 6a)}$$

and

$$\begin{aligned}&\delta F_f / \delta s_f = \tau_f + \varpi s_f - \psi_f - \Psi_{f,1} s_f + \Omega_{f,2} n_{f,p} + \Omega_{f,1}(s_{p,a} - s_p) + \Psi_{1,2} s_{a,f}, + \Psi_{1,3} o_f + \Psi_{f,4} l_f + \Omega_{p3} \lambda_{f,2} = 0\\ &\delta F_f / \delta n_{f,p} = \Phi_{f1} s_f - \Omega_{f,3} \lambda_{f1} = 0\\ &\delta F_f / \delta \lambda_{f,1} = s_p - s_{p,a} - \Omega_{f,3} n_{p,f} - \Omega_{f,2} \dot{S}_f = 0\\ &\delta F_f / \delta \lambda_{f,2} = 1'\Omega_{T,f}(s_f + s_{a,f}) + 1'\Omega_{T,p} s_p - o_h - o_e = 0\end{aligned} \quad \text{(Eq. 6b)}$$

For convenience we drop derivatives. As above introduced, composition criteria of plankton and fish species are given by the resource balance:

$$o_0 + o_h = 1' o_f + 1' o_{a,f} + 1' o_p = 1'\Omega_{T,f}(s_f + s_{a,f}) + 1'\Omega_{T,p} s_p \quad \text{(Eq. 6c).}$$

By (Eq. 6a, b, and c) we receive a 'new' determination of 'behaviour' that includes an exchange system with humans, i.e. labour, aquaculture residues, organic wastes and oxygen are now involved in an exchange (recycling). The system refers to an introduced restriction on oxygen. It is structured according to endogenous variables, which depict the eco-system as related to fitness and service; exogenous variables, which are not subject to decisions, made by humans as services, dysfunctional elements, and payments for service, which are endogenous. An appendix gives a mathematical reformulation of the system using an upper level matrix organisation of the three types of variables.

Second introduction of humans as principal

As already mentioned, humans decide on offering labour, determining aquaculture expansion, and on deliberately looking into waste disposal in aquatic eco-systems. For humans, labour dedicated to nature either creates opportunity costs or disutility. But maybe labour is necessary to offset negative impacts. At least humans can steer or control the eco-system service as been outline above. We foresee a labour constraint and a special negative amenity of work for nature. Oxygen can be bought on a market. In this respect we can expand system boundaries. Note, in the beginning we sketched a full utilisation of oxygen by nature that did not recognise aquaculture; nature was free in 'determining' species. Now aquaculture shall occupy a territory. It means the oxygen level is endogenously optimised. This requires an inclusion of functional elements that specify occupation and water use in an aquatic eco-system.

$$U_a = p_s s_{a,f} - p_m n_m - p_o o_h - C_a(s_{a,f}, s_f, s_{a,p} + n_m, l_a) + \mu_{a,1} \cdot [1 - I'[l_a + l_f] \cdot 1] - \rho' l_f' \Phi_a l_f + \mu_{a,2}[o_0 + o_h - o_p - o_f - 1' \Phi_{f,1} s_{a,f}] \quad \text{(Eq. 7a)}$$

Equation (Eq. 7a), as extension of (Eq. 4), caters for purchases of oxygen and for labour use. For interpretation of the objective, as those of a principal, interactions between aquaculture and the natural system can either be specified as a production function, that foresees higher yields from maintained eco-system, plankton provision, etc. or expressed as a cost approach that assumes already an internal optimum for means of production other the than nature related variables. We take the cost approach and make only reactions to endogenous nature, whereas the access to plankton and the health increase is a first dividend. To solve it we need behaviour.

Furthermore, we must specify the second dividend more explicitly by adding a cost reduction in the recycling industry's objective function! In this respect we primarily focus on a reduction of waste disposal costs. Nature shall provide a service by substituting artificial cleaning. Treatment facilities are minimised or are potentially not needed. Though, as an essential element, again, labour has to be introduced. We foresee two types of labour costs: one is reduced labour in the artificial treatment; the other is increased labour towards supporting nature in its capacity to recycle nutrients. We assume a net reduction, i.e. costs that already exist are reduced, which means less net-labour is our goal. Next, the organic waste recycling industry has to recognise a balance of waste to be recycled. Importantly, technical instead of biological degradation is costly. We assume a price for all equipments to have a reference. For any further contemplation, a waste management unit shall have the following objective function (Eq. 7):

$$U_w = \mu_w[1'(s_e + s^*_{a,f} - \Omega_{w,p} n_{w,p} - s_m)] - p_e l_e + \mu_{w,1}[1 - I'[l_e + l_p] \cdot 1] - \rho' l_p' \Phi_{f,1} l_p + (C_o - C_w(l_e, \Omega_{w,p} n_{w,p}, s_{a,f})) - p_m s_m \quad \text{(7.b)}$$

where additionally:

U_w = utility or cost of waste treatment measured as profit
$s_{e+}s_{a,f}$ = vector of waste to be recycled from organic material and fish as food from households
$n_{w,p}$ = vector of nutrient equivalent waste to be recycled as plankton of an aquatic system
s_m = vector of waste exogenously recycled
C_o = reference costs
l_d = labour for waste compartment of nature
l_e = labour for exogenous recycling

For relevance and flexibility of this approach: (1) We impose a certain level of organic waste s_e, exogenous to the system, which is to be recycled and depends on the scale of the human activities (incl. number of humans). (2) This organic waste has to be processed. Eq. (7b) includes it as categories i.e. either waste can be technically recycled (burnt or dumped) or used as organic products converted into nutrients $n_{w,p}$. For the evaluation μ_w gives a society's costs getting rid of waste (having less waste gives lower opportunity costs). Alternatively, we could think of an entropy measurement, but that is difficult to measure. (3) By additional food production from aquaculture for human use, $s_{f,a}$ i.e. fish, we add cost in recycling. However, (4) as a reference, waste can be taken out of the local system (not infiltrated into a lake, estuary, etc.) by s_m. s_m is expensive, i.e. it means external dumping, and ecologically it is entropy increasing. Remember eq. (7) is an economic approach and decisions are geared towards minimal costs of disposal. With respect to ecological optimisation the system may react differently. An entropy increase is unavoidable, but perhaps also to be minimised.

Finally, some remarks are necessary on (1) procedures as well as on equilibria or steady state in dynamics, (2) on oxygen as system boundary and labour as input, and (3) also with respect to a preliminary closure of the model. We think that human labour determines the ability to acquire resources. Then, assuming proportionality between resource (aquaculture) and the number of aquaculture farmers or labourers, the question is how to regress to a labour economy problem. Note in this case, the number of humans to be fed is at the core. This might be the easiest way to close the model and think about sustainability because we must feed humans with fish. In contrast, if the system is strongly driven by external labour cost, as currently the case, and labour availability changes, requests for closure also change: Then money flows become involved. Notice further, the above determination of the objective function is an abbreviation of a more complex exchange system within the human sphere; for the moment we only consider profits from aquaculture and labour as given within the food sector. Alternatively labour could be purchased at a price μ, which is the shadow price of labour. This is in line with an open trade regime for fish; whereby we, humans, need to sell food to buy other food; fish and labour are tradable. Apparently, in such case the number of people to be fed does not matter; instead what is wanted is profit! In a modern system the opportunity costs count, which means that we can show how the system is driven by the price of external feed in aquaculture, labour costs, fuel, etc.; and i.e. the system will smoothly respond with increased recycling costs, and we can show how the price of nature service derives from the ecosystem and will change. With no trade, simulations will be different, i.e. traditional.

Interaction of humans and nature and setting up a principal-agent scheme

The next point to be clarified concerns the procedures and knowledge prevailing in the system. We assume, farmers "know" the eco-system and optimise according to prevailing principles in system (Eq. 6). This requires a description of the equilibrium or steady state as dependent on instrument variables, known to farmers and waste mangers (App.). Though, in practice, that might be difficult, we assume full knowledge. We think that the problem can be reduced to labour "l_p and l_f" as well as production decision of farmers "$s_{a,f}$, n_m, $n_{w,p}$ and o_h". Labour and nutrients contribute positively to the "behaviour" of the eco-system, aquaculture negatively. A closure requires that the human sector determines food production and plankton. Next, we reconsider the structure of exchange as a principal-agent relationship. A principal-agent relationship [10] uses an incentive structure to get a service. It starts with an agent behaviour reckoning the agent's objective and response. This means that the system behaviour, as described above, has to be condensed into service and payment. For contemplation: normally the agent is a human being; but even in the context of human behaviour the concept of an objective function merely serves as a tool to find reactions to incentives, and it can be a physical exchange. In a context of human and nature we recognise two "quasi" objective functions (Eq. 1a' and b'), add them, and see what is the reaction of exchanging labour for service (plankton) and delivery (fish) as related to (Eq. 6). Structurally, we retrieve individual and joint behaviour of system compartments. System (Eq. 6) qualifies fitness as a goal being revealed from behaviour, i.e. the task is to insert the dependency of endogenous variables in human objective functions looking for maximum fitness. Note, we have also to include negative incentives, as $n_{w,p}$ and $s_{a,f}$ prevalence; though a participation constraint will assure mutual increase of fitness. For this aspect it is important to have a reference for fitness.

Structurally for (Eq. 6: App.) we receive a presentation that primarily depends on the exchange variables l_p, l_f, o_h, n_m, $n_{w,p}$, and $s_{a,f}$. With respect to labour l_p, l_f, and nutrients n_m, things are clear: Nature is in a newly established position that it can "ask" for labour in exchange for nutrients. Vice versa, fitness orientation tells that, if we deliver more nutrients, it provides more service. With respect to recycling organic matter $n_{w,p}$ things are not that clear. We consider nature as offering a certain potential of recycling, i.e. we calculate optimal fitness as a conjectural variation of acceptance. Organic waste is considered negatively if it is too much and fitness poses problems: more organics need more labour. In contrast fish feed and fish residues are considered positive, i.e. they are similar to natural products. By that we assume fish farming is partly in favour of nature. Remember humans, in this "model world", work for their own benefit. Since they "work" together with nature", they do not fully explore their power to squeeze nature. Instead, the injection of organic waste into the natural system is subject to costs which in turn reduce welfare. Humans bear a burden if they use nature for recycling!

Finally, we have to clarify on the overall objective function of humans. We merge the objective function (Eq. 7a and 7b) simply by adding them up. As another opportunity, we may foresee a sequential solution, whereby aquaculture optimises, first, and waste management, second. Then waste management is a superior entity. In both cases aquaculture and waste management need behavioural equations for the endogenous determination of services.

Solution

To solve the problem we take the result from the Appendix on interaction and substitute variables in objective functions (7a and b) to receive a new set of objective functions (Eq. 8a and b):

$$\begin{aligned}U_a &= p_s s_{a,f} - p_m n_m - p_o o_h - C_a(s_{a,f}, s_{p,a} - \gamma_{21} l_f + \gamma_{22} l_p + \gamma_{23} o_h + \gamma_{24} n_m + \gamma_{25} s_{a,f} + \gamma_{26} n_{w,p}, s_{p,a} + n_m, \mathrm{l}_\mathrm{a})\\ &+ \mu_{a,1} \cdot [1 - I'[\mathrm{l}_\mathrm{a} + l_\mathrm{f}] \cdot 1] - \rho' \mathrm{l}_\mathrm{f}' \Phi_\mathrm{a} \mathrm{l}_\mathrm{f} + \mu_{a,2}[\mathrm{o}_0 + \mathrm{o}_h - 1'\Omega_{T,f}(\gamma_{11} l_f + \gamma_{12} l_p + \gamma_{13} o_h + \gamma_{14} n_m + \gamma_{15} s_{a,f} + \gamma_{16} n_{w,p}) \quad \text{(Eq. 8a)}\\ &+ 1'\Omega_{T,p}(\gamma_{11} l_f + \gamma_{12} l_p + \gamma_{13} o_h + \gamma_{14} n_m + \gamma_{15} s_{a,f} + \gamma_{16} n_{w,p}) - 1' \Phi_{\mathrm{f},1} s_{a,f}]\end{aligned}$$

Notably, this expression reduces farm behaviour to decision making on production ($s_{a,f}$: in aquaculture), labour (l_a: for nature), feed (n_m), and oxygen (o_h: for system). We also have to recognise that farmers need information about labour l_p and waste injection $n_{w,p}$ (by the waste industry). A simultaneous optimisation is necessary. The same applies to waste recycling. The objective function of the waste management unit also includes the eco-system reaction; it is:

$$\begin{aligned}U_w &= \mu_w[1'(s_e + (I - \Omega_{R,1})^{-1} s_{a,f} - \Omega_{w,p} \mathrm{n}_{w,p} - s_m)] - p_e l_e + \mu_{w,1}[1 - I'[\mathrm{l}_\mathrm{e} + \mathrm{l}_\mathrm{p}] \cdot 1] - \rho' \mathrm{l}_\mathrm{p}' \Phi_{\mathrm{f},1} \mathrm{l}_\mathrm{p} \quad \text{(Eq. 8b)}\\ &+ (C_o - C_w(\mathrm{l}_\mathrm{e}, \Omega_{w,p} \mathrm{n}_{w,p}, \gamma_{21} l_f + \gamma_{22} l_p + \gamma_{23} o_h + \gamma_{24} n_m + \gamma_{25} s_{a,f} + \gamma_{26} n_{w,p} - s_{p,a})) - p_m s_m\end{aligned}$$

This formulation reveals the necessity to follow a joint optimisation of agriculture and waste management systems. We see that decisions made by aquaculture appear in the objective function of the waste recycling sector and vice versa. The plankton use by aquaculture and labour are relevant. For the moment we simply follow the strategy of summing up profits in the farm and waste management sector. Furthermore we introduce quadratic cost functions as

$$C_a(.) = \psi_a' s_{a,f}' - s_{a,f}'[0.5\Psi_{a,1} s_{a,f} + \Psi_{a,2} l_a + \Psi_{a,2} n_m + \Psi_{a,3}(s_{p,a} - \gamma_{21} l_f + \gamma_{22} l_p + \gamma_{23} o_h + \gamma_{24} n_m + \gamma_{25} s_{a,f} + \gamma_{26} n_{w,p}) + \Psi_{a,1}(\mathrm{n}_\mathrm{m} + s_{\mathrm{pa}})] \quad \text{(Eq. 9a)}$$

and

$$C_w(.) = \psi_w' l_e - l_e'[0.5\Psi_{w,1} l_e + \Psi_{w,2} \Omega_{w,p} \mathrm{n}_{w,p} + \Psi_{w,3}(\gamma_{11} l_f + \gamma_{12} l_p + \gamma_{13} o_h + \gamma_{14} n_m + \gamma_{15} s_{a,f} + \gamma_{16} n_{w,p} - s_{p,a})] \quad \text{(Eq. 9b).}$$

Inserting functions (Eq. 9a and b) in our, to be optimised, objective functions (Eq. 8a and b) we receive behavioural equations for aquaculture and the waste management sector (Eq. 10a and b, as first derivatives). System (Eq. 10) can be simultaneously solved for all endogenous variables. Seven variables are in hands of humans: Four variables concern the allocation of labour (l_a,l_f, l_d,l_e), one is about food production ($s_{f,a}$), one about oxygen (o_h), and one about fish feed (n_m). To let the four compartments interact, we have to optimise “aquaculture” and “waste” simultaneously. For aquaculture we find optimal variables s_{af}, n_m, s_{ap}, l_f, l_a(derivatives are omitted):

$$p_f - \psi_a' - \Psi_{a,1} s_{a,f} - \Psi_{a,2} l_a - \Psi_{a,2} n_m - \Psi_{a,3}(s_{p,a} - \gamma_{21} l_f + \gamma_{22} l_p + \gamma_{23} o_h + \gamma_{24} n_m + \gamma_{25} s_{a,f} + \gamma_{26} n_{w,p}) - \Psi_{a,1}(\mathrm{n}_\mathrm{m} + \mathrm{s}_{\mathrm{pa}}) - \Phi_{\mathrm{f},1} 1\, \mu_{a,2} + (I - \Omega_{R,1})^{-1} \mu_w = 0$$

$$p_m - \Psi_{a,2} s_{f,a} + \Psi_{f,3}(\gamma_{45} + 1) s_{f,a} + \Psi_{a,1} n_m = 0$$

$$\Psi_{a,1} s_{p,a} + \Psi_{a,3} \mathrm{s}_{\mathrm{p,a}} = 0$$

$$1\mu_{a,1} + \Psi_{a,3} \gamma_{41} s_{f,a} + \Psi_{a,4} \mathrm{l}_a + \Phi_{a,1} \mathrm{l}_{a,1} = 0$$

$$1\mu_{a,2} + \Psi_{a,3}\gamma_{51}s_{f,a} + \Psi_{a,5}l_f = 0 \qquad \text{(Eq. 10a)}$$

and for the waste recycling and management sector we have o_h, l_e,. l_p, s_m, $n_{w,p}$:

$$\Psi_{f,3}\gamma_{13}s_{f,a} + \mu_{a,2} = 0$$

$$-p_e + \psi_w^{/} - \Psi_{w,1}l_e + \Psi_{w,3}\gamma_{12}l_p = 0$$

$$\mu_w + \Phi_{f,1}l_p + \Psi_{w,3}\gamma_{12}l_e = 0$$

$$-\mu_w + p_{w,2} = 0 \; \mu_w - \Psi_{w,2}\Omega_{w,p}l_e + \Psi_{w,3}(\gamma_{21}l_f + \gamma_{22}l_p + \gamma_{23}o_h + \gamma_{24}n_m + \gamma_{25}s_{a,f} + \gamma_{26}n_{w,p} - s_{p,a}) = 0 \qquad \text{(Eq. 10b)}$$

plus balances. Three equations or constraints on labour and oxygen (two for labour: farm labour and waste management; and one for oxygen) supplement the system. It is a linear system. Technically it is matter of matrix depiction to get a solution, preparing model (Eq. 10) for a final determination of variables. Given endogenous variables of human behaviour, we can finally predict ecological compartments. As a finishing remark on solutions, we should use variables of the resolved system to quantify participation constraints. Participation constraints are necessary conditions. They assure exchanges being beneficiary for nature and humans.

CLOSURE AND APPLICATION

In the given version, the economic system is an open system. Humans are involved in as much as they are producers of food (aquaculture), they seek profits from involving nature in food production, and as citizens (waste management) they seek profits from cheaper methods of waste disposal. Obviously this does not involve an explicit recognition of the number of humans. There is no closure of the system unless assuming that food produced is a constraint for population growth and also a constraint for labour. Both can still be freely adjusted. The model could be altered. We are able to restricted labour availability to food production. Hereby, technically, the number of variables to be freely optimised diminishes. In addition, the model so far does not include utility from food consumption, i.e. marginal utility is derived as a fixed food price, which means assuming a world-market driven determination of food prices. That is different if we do not allow food trade or do not have it. The same applies to waste. Given a certain cost for waste disposal, outside the system, we have an anchor that is described by a world market type of costs for waste management (trade). Such formulations are critical and raise questions beyond our approach. We have deliberately avoided such questions. There are pros and cons. (1) Food is traded because this is the current situation. (2) Those who seek a total analysis can include food provision and consumption by combining two regions. (3) It has to be acknowledged that it is difficult to define the system boundaries.

In a broacher context, we have also to tackle further questions on objective functions. To be clear, we used profits as human objectives, but the number of humans is beyond our analysis. A question would be to see alternatives in objectives for developing long run strategies and test survival rates for numbers of humans. Also we have to look at types of aquaculture. Especially some fish species do not rely on plankton nowadays; though they pollute. Such problems are to be addressed. Feed is imported and lakes have become a dumping ground for organics. We can include such situations by distinguishing livestock as another source of waste.

SUMMARY

The paper provided an outline for a model to measure the importance of nature services for humans. It pursues the idea of involving nature in organic waste recycling offering a double dividend. A double dividend means that we can get feed for aquaculture cheaper from plankton than from the outside, and nature offers also organic waste recycling for urban waste. Recycling is cheaper than dumping waste outside the system. We introduced four actors: plankton, fish, farmers and waste management. They interact and humans act as principle and nature as agent. The model is solved and labour and nature service are modelled as exchange. Nature is described by maximising fitness and humans maximize profits. The model shows how to calculate necessary payments (labour and oxygen) for nature service and how to optimise services simultaneously (feed and waste recycling). Furthermore, we made references to work on more closed models and how to design models for questions of system sustainability.

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APPENDIX

$$\begin{bmatrix} \Psi_{f,1}+\varpi & \Omega_{f,1} & \Omega_{f,2} & 0 & 0 & \Omega_{p3} \\ \Psi_{f,4}\Omega_{t,1} & \varpi+\Psi_{p,1} & \Omega_{p,1} & \Omega_{p2}0 & 0 & 0 \\ \Phi_{p,1} & 0 & 0 & 0 & \Omega_{f,1} & 0 \\ 0 & \Omega_{p2} & 1 & 0 & 0 & 0 \\ 0 & 1 & \Omega_{f,3} & 0 & 0 & 0 \\ \Omega_{t,1} & \Omega_{t,2}0 & 0 & 0 & 0 & 0 \end{bmatrix} . \begin{bmatrix} [s_f] \\ [s_p - s_{p,a}] \\ [n_{f,p}] \\ \lambda_{p,1} \\ \lambda_{f,1} \\ \lambda_{f,2} \end{bmatrix} =$$

$$\begin{bmatrix} 0 & \Psi_{p,4} & 0 & 0 & 0 & \Psi_{p,2} \\ \Psi_{f,4} & 0 & 0 & \Psi_{f,2}+\Omega_{p,1}\Omega_{t,2}[I-\Omega_{t,1}]^{-1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \Omega_{t,2}[I-\Omega_{t,1}]^{-1}0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} [l_f] \\ [l_p] \\ o_h \\ [s_{a,f}] \\ n_m \\ [n_{w,p}] \end{bmatrix} + \begin{bmatrix} 1 & 0 & \Psi_{p,3} & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \tau_d \\ \tau_a \\ n_x \\ o_t \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & \Omega_{p,2}0 \\ \Omega_{f2} & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \dot{S}_f \\ \dot{S}_p \end{bmatrix} \qquad \text{(A.1)}$$

There are two procedures: A dynamic system or steady states. ts later, behaviour is a

$$\begin{bmatrix} [s_f] \\ [s_p - s_{p,a}] \\ [n_{f,p}] \\ \lambda_{p,1} \\ \lambda_{f,1} \\ \lambda_{f,2} \end{bmatrix} = \begin{bmatrix} \gamma_{10} \\ \gamma_{20} \\ \gamma_{30} \\ \gamma_{40} \\ \gamma_{50} \\ \gamma_{60} \end{bmatrix} + \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{14} & \gamma_{15} & \gamma_{16} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{24} & \gamma_{25} & \gamma_{16} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{34} & \gamma_{35} & \gamma_{16} \\ \gamma_{41} & \gamma_{42} & \gamma_{43} & \gamma_{44} & \gamma_{45} & \gamma_{16} \\ \gamma_{51} & \gamma_{52} & \gamma_{53} & \gamma_{54} & \gamma_{55} & \gamma_{16} \\ \gamma_{61} & \gamma_{62} & \gamma_{63} & \gamma_{64} & \gamma_{65} & \gamma_{66} \end{bmatrix} \begin{bmatrix} [l_f] \\ [l_p] \\ [n_{w,p}] \\ o_h \\ [n_m] \\ [s_{a,f}] \end{bmatrix} + \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{14} & \gamma_{15} & \gamma_{16} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{24} & \gamma_{25} & \gamma_{16} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{34} & \gamma_{35} & \gamma_{16} \\ \gamma_{41} & \gamma_{42} & \gamma_{43} & \gamma_{44} & \gamma_{45} & \gamma_{16} \\ \gamma_{51} & \gamma_{52} & \gamma_{53} & \gamma_{54} & \gamma_{55} & \gamma_{16} \\ \gamma_{61} & \gamma_{62} & \gamma_{63} & \gamma_{64} & \gamma_{65} & \gamma_{66} \end{bmatrix} \begin{bmatrix} \tau_d \\ \tau_a \\ n_x \\ o_t \end{bmatrix} + [x] \qquad \text{(A.2)}$$

linear system prevails. We can split decomposition and accumulation and variables for the objective function appear.